Networked capabilities for sustainable energy solutions

Parraguez Ruiz, Pedro; Maier, Anja

Published in:
Accelerating the clean energy revolution - perspectives on innovation challenges

Publication date:
2018

Document Version
Publisher's PDF, also known as Version of record

Citation (APA):
Parraguez Ruiz, P., & Maier, A. (2018). Networked capabilities for sustainable energy solutions. In *Accelerating the clean energy revolution - perspectives on innovation challenges: DTU International Energy Report 2018* (pp. 29-35). Technical University of Denmark.

Chapter 4

Networked Capabilities for Sustainable Energy Solutions

By **Pedro Parraguez** and **Anja Maier**, Department of Management Engineering, Technical University of Denmark

A network overview of sustainable energy capabilities

The research, development and deployment of large-scale sustainable energy solutions is one of the greatest social challenges of our time. Tackling this challenge requires a systems perspective revealing the connections between the wealth of relevant scientific knowledge available across the natural engineering and social sciences. It also requires new approaches to orchestrate and integrate complex systems into uncertain environments while simultaneously taking regulations, economic concerns and changes in human behaviour into account.

For these reasons, now more than ever we need to leverage and develop further all the potential of R&D ecosystems effectively and efficiently. To do so, we propose to start by understanding the capabilities embedded in existing R&D networks and the connections between the resources and the knowledge that those networks already contain.

To illustrate this with a concrete example, this chapter provides a network overview of the capabilities that are available through DTU's R&D ecosystem to research, develop and deploy clean energy solutions. To provide this overview, this chapter offers a data-driven system analysis of the eight energy challenges covered in this report. These challenges are inspired by Mission Innovation (2017) and consist of "Smart Grids", "Off-Grid Access to Electricity", "Carbon Capture", "Sustainable Biofuels", "Converting Sunlight", "Clean Energy Materials", "Affordable Heating and Cooling of Buildings" and "Energy Storage".

Challenges and opportunities

Due to the rapid development of highly specialised technologies, mounting environmental challenges and heightened competition, there is increased pressure to develop more sustainable energy solutions [2; 3]. For individual companies acting on their own, it is often impossible to improve, develop and/or deploy new energy solutions. The growing consensus appears to be that sustainable energy solutions require concerted inter-organisational efforts to combine existing resources and capabilities [4–6]. In fact, several industrial practices connected to the inter-organisational development of cleaner and more sustainable production systems have been identified [e.g. 7; 8]. Such multi-stakeholder industrial practices include projects described as industrial symbiosis, circular economy, eco-industrial parks, eco-clusters and sustainable supply chains, as well as other initiatives described as green partnerships and ad-hoc collaborations aimed to support sustainable energy. More generally, outside the cleaner production domain, these types of multi-stakeholder practices can be framed as open innovation projects, joint ventures, alliances, and other forms of inter-organisational collaborative projects [e.g. 9; 10].

Among the many technology sectors connected to the development of more sustainable energy systems are energy efficiency, energy storage, carbon capture, heating and cooling, intelligent energy, smart grids, wind, solar and other renewable energies, and bioenergy [11; 12]. This industrial landscape constitutes a diverse set of evolving interlocked technologies and organisations, which are unfortunately often misrepresented by the currently rigid industrial categorisation schemes and traditional industrial cluster analyses [13–15].

To foster the development of new sustainable energy solutions, numerous national and international innovation networks, cluster organisations, associations and funding programmes have been created. These initiatives are supported by industry, the public sector and non-governmental organisations (NGOs) with the purpose of facilitating information flow, coordination and access to resources [16]. Recent examples of such initiatives include multi-stakeholder partnerships by the United Nations to support fulfilment of the Sustainable Development Goals, the Danish project "Complex Cleantech Solutions" and its successor "CLEAN Solutions", UNIDO's "Global Cleantech Innovation Programme", the European Union's "Climate Knowledge and Innovation Community" (Climate KIC), Innoenergy and the "Sustainable Energy for All" initiative, to name just a few.

Despite the potential envisaged, the resources invested and the broad public and private backing that inter-organisational support initiatives receive, both the companies participating in these projects and the organisations supporting such initiatives report problems related to the challenge of developing inter-organisational projects and identifying capabilities to fill technological gaps in a timely manner [2;17]. Recurrent problems include a limited overview of the industrial landscape of technological capabilities [18; 19], difficulties in finding and assessing collaboration partners based on capability complementarities [20; 21], difficulties in both intra- and inter-organisational cross-disciplinary collaboration [22], and tensions between intellectual property rights and open collaboration [23]. These problems are not always related to the exchange of materials or energy per se, but rather to the exchange of information and non-material resources in the form of knowledge, know-how and technologies [10; 24]. As a consequence, we see an increased need for a more systematic mapping of the capabilities found in R&D ecosystems in order to achieve a better overview of the networks of technologies, knowledge and know-how that are available for solving complex socio-technical problems such as the development and implementation of new sustainable energy solutions.

In this context, R&D ecosystems can be described as sets of research and development organisations embedded in a network and characterised by inter-organisational relations, shared objectives, shared resources and/or exchanges of materials, energy and information. Relations that can lead to beneficial interactions and inter-dependencies among the participating organisations and their environment [25].

Mapping DTU's R&D ecosystem of sustainable energy solutions

To better understand the capabilities available to research and develop sustainable energy solutions and to map the relationships between the eight challenges, we have analysed DTU's energy-related solutions through a curated data set of more than 740 ISI publications, sixteen patents, and thirty EU-funded projects ranging from the 5th Framework Programme (FP5) to Horizon 2020. All of these records have at least one participant from DTU and include content relevant to at least one of the eight sustainable energy challenges explored in this report.

The procedure for filtering relevant publications, patents and EU projects consisted in applying a global content filter to each of the three databases (publications, patents, projects), followed by a manual screening of the results to discard false positives. In Boolean form, the keyword-based search used for this study was:

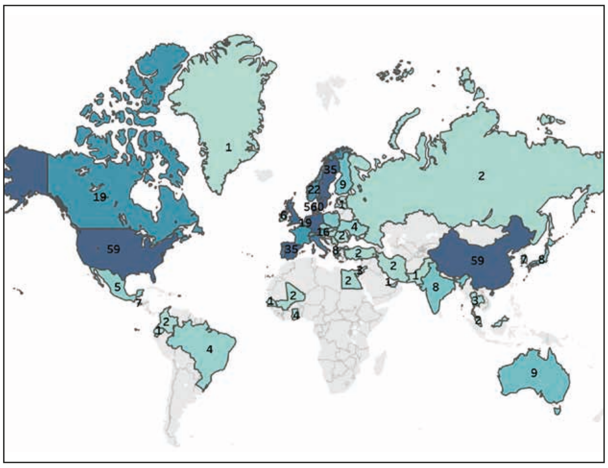
"Smart Grid" OR ("off-grid" AND electric*) OR "carbon capture" OR "biofuel" OR "convert sunlight" OR "solar energy" OR "energy materials" OR [(heating OR cooling) AND (affordable OR cheap OR sustainable)] OR "energy storage" OR "smart energy" OR ("mini-grid" AND electric*) OR ("micro-grid" AND electric*) OR (catalysis AND energy) OR "solar fuels" OR "integrated energy systems" OR "energy system analysis" OR "energy access" OR electrification OR (electricity AND "developing countries") OR "solar home systems".

The results of this search, although not exhaustive, provide records from diverse sources and fields large enough to allow a representative overview of content and collaborations over the last twenty years. In total, these records connect DTU with more than 55 countries and 500 organisations. Figure 1 provides a visual summary of the diverse set of regions and organisations that has formed part of DTU's sustainable energy R&D ecosystem since 2005.

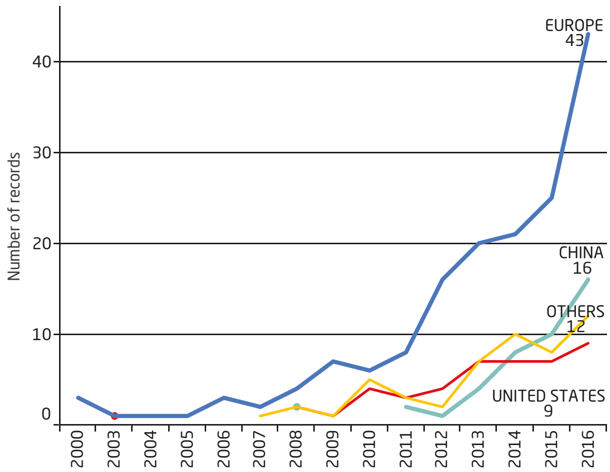
The main question explored in Figure 1 is, what have been DTU's collaborations in the area of sustainable energy solutions, and how are they distributed geographically and over time?

In Figure 1, we can observe the growing relevance of collaborations with Asia, which in 2015 exceeded the volume of collaborations with the United States. We can also observe a steady rise in the number and diversity of collaborations, indicating an increasingly complex R&D ecosystem. For example, from 2010 onwards, the primary pool of countries and organisations changes from being mainly associated with developed European countries to a much broader base that includes Asia, southern Europe, the United States and several emerging countries. This trend reflects an expansion in the number of research areas covered, increased ambition levels and the significant increase of R&D investment in this area by both developed and developing countries, a trend that is corroborated by the latest world figures in the "Global Trends in Renewable Energy Investment Report" [26].

DTU's collaborations: Geographical distribution



DTU's collaborations: Evolution of records over time



Treemap of DTU's most frequent collaborations by number of records

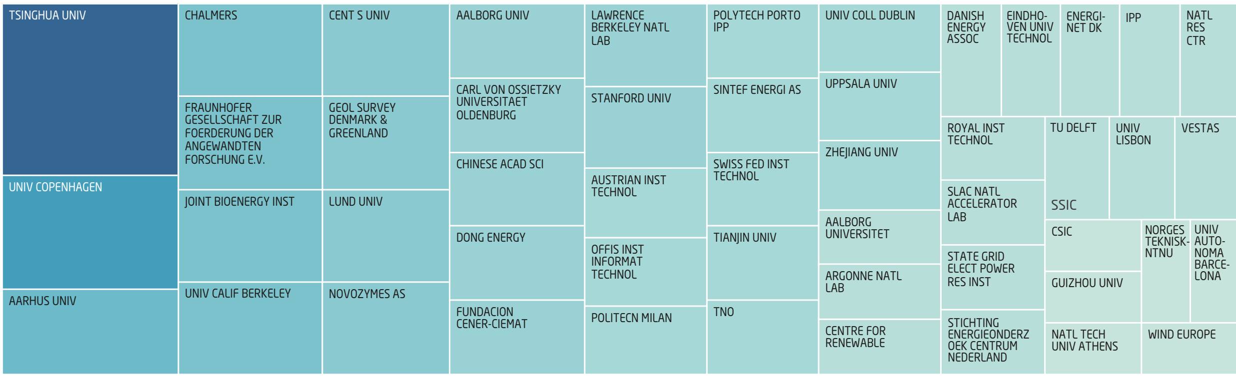


Figure 1. The top left panel shows the geographical distribution of DTU collaborations on the world map. The numbers show the records associated with each region. The top right panel plots the number of records over time per geographical region. The bottom panel shows a tree map with the most frequent collaborations over time. The size represents the number of records connected to each organisation.

Mapping the eight sustainable energy challenges and their relations

To identify and map the relations between the eight sustainable energy challenges, we performed a content co-occurrence analysis, following the method described by Van Eck and Waltman [27]. In this analysis, DTU's R&D ecosystem is modelled as a network. The nodes are keywords extracted from the content of each record in our database. In our case, after normalising the keywords, we gathered over 4,000 terms. The edges between the keywords represent co-occurrence relations, of which we reach over 25.000 links. Here, a connection between two keywords exists if they are mentioned together in at least one record. The more frequently two keywords are mentioned together, the stronger the connection between them.

As the whole analysis was performed on the previously filtered database, we know that each record is relevant for at least one of the challenges. In order to identify areas in the network that are primarily associated with one or more of the challenges, we performed a cluster analysis using Waltman, Van Eck, and Noyons's [28] method to cluster bibliometric networks. Each cluster represents a topic area, where the connections between the keywords are stronger within the cluster to which they are assigned than between other clusters. Having identified the main clusters, a qualitative inspection of the collection of keywords in each cluster allows the clusters to be mapped to each of the eight challenges. As a result, the left panel in Figure 2 shows the relations between the eight challenges as a network, while the right panel plots the main keywords associated with each challenge as an evolution across a fifteen-year timespan.

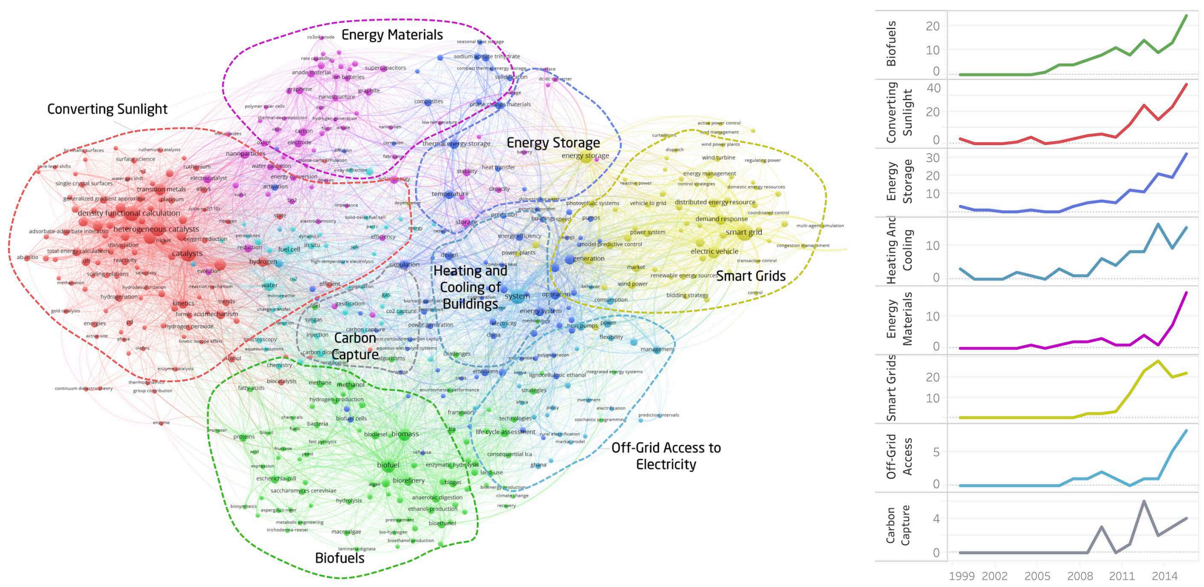


Figure 2. Left panel: network of keywords and co-occurrence relations between those keywords. The size of the nodes represents the frequency of each keyword. The colours show the keyword clusters that are used to identify areas of the network associated with the eight challenges. Right panel: evolution over time of each challenge in terms of the raw frequency of the main keywords associated with the respective challenge.

Through the cluster map in the left panel of Figure 2, we see that there is only one network component with high connectivity within and between the clusters. This can be taken as a sign of the strong topical ties between the eight challenges in DTU's overall R&D ecosystem. We also found that, if we divide the network into two sides, some interesting patterns emerge.

The right side of the network concentrates challenge areas where research and development often interface with policy, human behaviour, regulations and large engineering-system integrations. For example, the clusters on the right side, associated with the challenges of energy storage, heating and cooling, smart grid and off-grid access to electricity, are frequently connected to keywords such as systems, integration, behaviour, uncertainty and management. Another interesting feature of this region is the position that energy storage occupies between smart grids and clean energy materials. This can be explained by the dependencies between different energy storage solutions, the advanced new materials required to make them possible, and the implications of this for the future of the overall energy grid. Such dependencies influence aspects such as the degree to which the energy grid becomes more or less centralised, which in its turn is contingent on the existence of competitive distributed energy storage solutions.

The left of the network concentrates challenge areas where research and development often interface with the natural sciences, including the life sciences, physics and chemistry. For example, the clusters on the left associated with the challenges of clean energy materials, converting sunlight, carbon capture, and sustainable biofuels, are more frequently connected with keywords that reference elements, molecules or natural processes, including terms such as graphene, composites, fermentation, catalysts and nanotubes. This left side of the overall network can be divided further into an upper and a lower side. The upper side is mostly connected to disciplines such as material science, physics, nanotechnology and photonics. In turn, the lower side is connected to disciplines such as bioengineering, chemical engineering and bio-sciences. For example, within DTU's R&D ecosystem, a large area of research on converting sunlight takes the form of advances in electrocatalysis and photocatalysis that are of interest for sustainable energy conversion and fuel production. In terms of the different clusters and their mapping on to Mission Innovation challenges, energy materials are strongly connected to both energy storage and converting sunlight, making it hard to distinguish a clear unique boundary. This is due to the important enabling role that energy materials play in both challenge areas.

In terms of the evolution over time of the topics associated with each of the eight challenges (right side of Figure 2), we can identify two groups: one group that contains records dating back to 2000, shown in the first five challenges from top to bottom; and a second group that contains the remaining three challenges from top to bottom, where the first records start appearing around 2008. Within each of these two groups, the patterns are relatively similar. With the exception of the heating and cooling of buildings, the first group is mostly connected to the challenges of energy production and storage. In turn, the second group is about the delivery of energy, using more efficient and effective grids, and the challenge of capturing CO_2, not only to mitigate current emissions, but to reduce the overall accumulated stock of CO_2. In this way, this temporal progression appears to follow a natural increase in ambitions and R&D investment at DTU.

Beyond the features for each region of the network and their dynamics reported above, it is important to note that the eight challenges are highly interconnected. The differences identified are changes within a spectrum, rather than features that can be easily allocated to independent science fields or technologies. Research areas involved range from fundamental research on new energy materials and studies of metabolic pathways at the cellular level, all the way to the deployment of smart energy grids and the study of decision-support systems to ease the adoption of best energy practices. Furthermore, we have shown that the eight challenges come together as part of an entire R&D ecosystem that allows sustainable energy to be developed and delivered at scale.

Conclusion and highlights

The data-driven exploration of DTU's R&D ecosystem for sustainable energy solutions presented in this chapter provides a glimpse into the complex processes and interactions that allow us to research, design and deploy new energy solutions. It highlights the overall connectedness between the eight sustainable innovation challenges and the importance of applying a system perspective in connecting scientific fields and technologies. Furthermore, the socio-technical characteristics of the knowledge and technologies required to move from research to real-world impacts are explicitly visualised. Evidence of this is shown through the integration into one and the same network that covers the spectrum of the natural and engineering sciences, as well as elements of the social sciences.

References

1. 1. Mission Innovation. Mission Innovation Challenges: Progress and Highlights. 2017.
2. 2. OECD. OECD Studies on Environmental Innovation Better Policies to Support Eco-innovation. OECD Publishing; 2011. 304 p.
3. 3. OECD / International Energy Agency. Nordic Energy Technology Perspectives. Paris; 2016.
4. 4. Roscoe S, Cousins PD, Lamming RC. Developing eco-innovations: A three-stage typology of supply networks. J Clean Prod. 2016;112:1948–59.
5. 5. Schiller F, Penn AS, Basson L. Analyzing networks in industrial ecology - A review of Social-Material Network Analyses. J Clean Prod. 2014;76:1–11.
6. 6. Dovì VG, Friedler F, Huisingh D, Klemeš JJ. Cleaner energy for sustainable future. J Clean Prod. 2009;17(10):889–95.
7. 7. Van Bommel HWM. A conceptual framework for analyzing sustainability strategies in industrial supply networks from an innovation perspective. J Clean Prod. 2011;19(8):895–904.
8. 8. OECD. Eco-innovation in industry: enabling green growth. Paris: OECD; 2009. 276 p.
9. 9. Gulati R, Gargiulo M. Where Do Interorganizational Networks Come From? Am J Sociol. 1999 Mar;104(5):1439–1438.
10. 10. Hagedorn J. Understanding the rationale of strategic technology partnering: interorganisational modes of co-operation and sectorial differences. Strateg Manag J. 1993;14(January 1992):371–85.
11. 11. State of Green. State of Green Cleantech Registry [Internet]. 2017 [cited 2017 Feb 22]. Available from: https://stateofgreen.com/en
12. 12. Gray M, Caprotti F. Cleantech clusters and the promotion of the low carbon transition: criteria for success and evidence from Copenhagen, Masdar and online platforms. Carbon Manag. 2011;2(5):529–38.
13. 13. Salerno M, Lambkin A, Minola T. Key Success Factors in supporting Clean Tech start-ups: A General Framework and an Italian experience. In: Laudon, M and Laird, DL and Romanowicz B, editor. Clean Technology 2009. 2009. p. 385–8.
14. 14. Parad M. The Global Cleantech Innovation Index 2014. 2014.
15. 15. Andersen JW, Parraguez P, Maier AM. NetSights: Network Insights for Collaborative Sustainable Production – A Practical Guide. Copenhagen; 2016. 52 p.
16. 16. Senge PM, Lichtenstein BB, Kaeufer K, Bradbury H, Carroll JS. Collaborating for systemic change. MIT Sloan Manag Rev. 2007;48(2):44–53+92.
17. 17. Waddell S. Societal Change Systems: A Framework to Address Wicked Problems. J Appl Behav Sci. 2016 Dec 1;52(4):422–49.
18. 18. Prašnikar J, Lisjak M, Buhovac AR, Štembergar M. Identifying and Exploiting the Inter relationships between Technological and Marketing Capabilities. Long Range Plann. 2008;41(5):530–54.
19. 19. Lall S. Technological capabilities and industrialization. World Dev. 1992;20(2):165–86.
20. 20. Parraguez P, Maier AM. Network Insights for Partner Selection in Inter-organisational New Product Development Projects. In: Dorian M, Mario S, Neven P, Nenad B, editors. Proceedings of International Design Conference, DESIGN. Dubrovnik, Croatia; 2016. p. 1095–104.
21. 21. Büyüközkan G, Arsenyan J, Büyüközkana G, Arsenyanb J. Collaborative product development: a literature overview. Prod Plan Control. 2011;(March 2012):37–41.
22. 22. Jeffrey P. Smoothing the Waters: Observations on the Process of Cross-Disciplinary Research Collaboration. Soc Stud Sci. 2003;33(4):539–62.
23. 23. Blomqvist K, Hurmelinna P, Seppänen R. Playing the collaboration game right - Balancing trust and contracting. Technovation. 2005;25(5):497–504.
24. 24. Mirata M. Experiences from early stages of a national industrial symbiosis programme in the UK: Determinants and coordination challenges. J Clean Prod. 2004;12(8–10):967–83.
25. 25. Ruth M, Davidsdottir B. The dynamics of regions and networks in industrial ecosystems. Edward Elgar; 2009. 238 p.
26. 26. UNEP Collaborating Centre for Climate and Sustainable Energy Finance. Global Trends in Renewable Energy Investment 2017. 2017.
27. 27. Van Eck NJ, Waltman L. Visualizing Bibliometric Networks. Measuring Scholarly Impact. 2014. 285-320 p.
28. 28. Waltman L, Van Eck NJ, Noyons ECM. A unified approach to mapping and clustering of bibliometric networks. J Informetr. 2010;4(4):629–35.

DTU International Energy Report 2018
Accellerating the Clean Energy Revolution
- Perspectives on Innovation Challenges

May 2018

Edited by
Birte Holst Jørgensen and Katrine Krogh Andersen, Technical University of Denmark
Elisabeth J. Wilson, Dartmouth College

Reviewed by
William D'haeseleer, KU Leuven

Design
Rosendahls a/s

Print
Rosendahls a/s

ISBN 978-87-93458-57-4